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Large second-harmonic generation in thermally poled silica waveguides

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Abstract: We report the observation of very large second-harmonic signals from thermally poled silica waveguide samples. Secondary Ion Mass Spectrometry measurements show that significant amounts of silver ions are injected from the top electrode during poling.

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1. Introduction

Active nonlinear optical devices based on poled silica [1] would offer an attractive alternative to expensive nonlinear crystals, such as LiNbO_3 . In this work we present new results indicating that poling of silica waveguides gives nonlinear coefficients within 30% of those for LiNbO_3 . To the best of our knowledge the results represent a world record for poling of silica-based waveguides.

2. Sample preparation

Silica-based channel waveguides (see Fig.1) were produced with Plasma Enhanced Chemical Vapor Deposition (PECVD) and subsequent UV-writing [2]. A silver-containing paint was used as top electrode while the silicon wafer was used as bottom electrode. One sample was (positively) poled by applying +1 kV to the top electrode at 430°C.

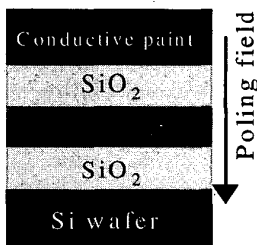


Fig. 1. Sample grown by PECVD with top electrode of conducting silver paint. Field direction indicated for positive poling.

Another sample was (negatively) poled using ± 1 kV. The samples were both poled for 25 minutes and then cooled to room temperature with the voltage still on. After poling, the samples were cleaved through the poled area and the distribution of the second-order nonlinearity (SON) along the coordinate parallel to the poling field was investigated.

3. Optical characterization

A 755 ± 7 nm pump beam (spot size $\sim 2 \mu\text{m}$) with normal incidence was scanned across the glass layers in steps of $0.25 \mu\text{m}$ and the reflected second-harmonic (SHG) signal was recorded. One of the recorded profiles is shown in Fig. 2.

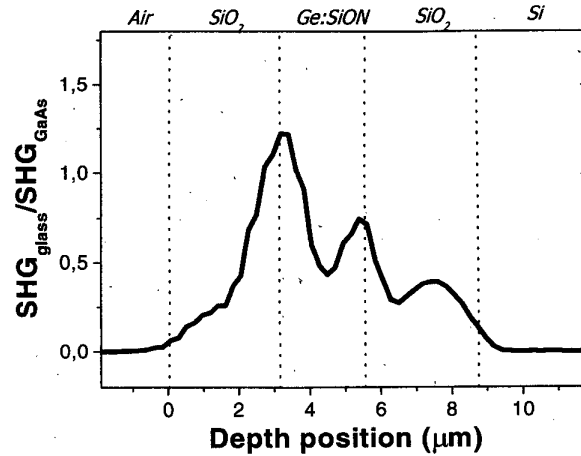


Fig. 2. SHG depth profile of positively poled waveguide sample.

The setup was calibrated by measuring the SHG from the (311) surface of GaAs under the same experimental conditions. For the positively poled sample the peak value of $\chi^{(2)}(-2\omega; \omega, \omega)$ is estimated to be 22 ± 8 pm/V, while the peak value for the negatively poled sample was 0.6 ± 0.2 pm/V. These estimations are based on the formalism developed by Bloembergen [3] and the measurements of $\chi^{(2)}(-2\omega; \omega, \omega)$ for GaAs reported in reference [4]. In contrast to the large SHG signal, only small linear electro-optic (LEO) effects were detected in the channel waveguides of the positively poled sample. The negatively poled sample showed a LEO coefficient of $\chi^{(2)}(-\omega; \omega, 0) = 0.05$ pm/V.

4. Poling induced ion migration

Secondary Ion Mass Spectrometry (SIMS) measurements show that large amounts of positive ions enter the positively poled sample during poling, as illustrated in Fig. 3. In particular, silver (Ag) is present in high concentration, with a peak at the lower core/cladding interface corresponding to 30 atomic %. For the negatively poled sample we observe no ion migration.

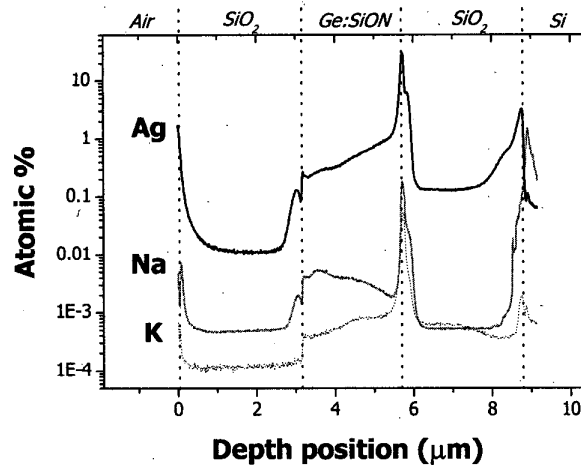


Fig. 3. SIMS concentration depth profiles for the positively poled sample.

5. Conclusion

We believe that the high SON is related to the injection of silver. It is known that silica containing silver nano-scale clusters can exhibit extremely large resonant nonlinear optical effects [5,6]. Comparison of many SHG depths profiles and SIMS concentration profiles, however, did not reveal a simple consistent correlation between the Ag concentration and the level of SHG. One may speculate that the effect is due to a combination of a large $\chi^{(3)}$ from the silver and an internal electric field resulting from the inhomogeneous ion concentration profiles.

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